

# Comment on Japanese Detection of Air Fluorescence Light from a Cosmic Ray Shower in 1969

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## Abstract

We examine the claim made by Hara et al.[1] in 1969 of the observation of a  $10^{19}$ eV cosmic ray extensive air shower using the air fluorescence technique. We find that it is likely that fluorescence light was observed, confirming this as the first such observation. The work of Hara et al. and their friendly competitors at Cornell University paved the way for modern experiments like the Pierre Auger Observatory and the Telescope Array.

## 1 Introduction

Investigations into the feasibility of detecting air fluorescence light from extensive air showers were conducted in the 1960's by groups led by Suga in Japan and Greisen in the United States. Results from the Japanese experiment, reported by Hara et al.[1] in 1969, are reviewed here. In that report, the authors say "One event is very likely due to the atmospheric scintillation [fluorescence] light from an air shower whose primary energy and distance are about  $10^{19}$ eV and 3 km, respectively". This was the first reported observation of fluorescence light from an air shower. The purpose of the present short note is to review this observation in the light of our modern understanding of fluorescence detection.

The Japanese experiment ran at the Dodaira Observatory (altitude 876 m) for a period of 5 months from December 1968. The fluorescence telescope consisted of a 1.6 m diameter Fresnel lens focussing light onto a camera of 24 PMTs, each of which imaged a  $4.5^\circ$  degree portion of the sky. For the observation described here, the telescope with its field of view of  $23^\circ \times 20^\circ$  was centered at an elevation of  $30^\circ$ . The design was similar to Greisen's Cornell telescope [2]. However the Japanese design had the advantage of a larger Fresnel lens, and faster electronics. The rise and fall-times of pulses on the cathode-ray tube displays were  $0.12\mu\text{s}$  and  $0.2\mu\text{s}$  respectively.

The potential fluorescence observation (event #12 in Fig 3 of [1]) triggered 8 PMTs with an angular track length of  $18.4^\circ$  and a duration of  $1.9\mu\text{s}$ . In the next section we review the event geometry before considering the shape of the light profile received at the telescope.

## 2 Event Geometry

I have taken the PMT trigger times from Fig 3 of [1], and using an estimate of the PMT pointing directions, I have made fits to the standard timing equation,

$$t_i = t_0 + \frac{R_p}{c} \tan\left(\frac{\chi_0 - \chi_i}{2}\right)$$

to extract shower axis parameters  $t_0$ ,  $R_p$  and  $\chi_0$  from the eight  $(\chi_i, t_i)$  data points. I have assumed a vertical shower-detector plane (SDP), and I have guessed at a timing uncertainty of  $0.05\mu\text{s}$  for each point. The SDP and the axis parameters are illustrated in Figure 1.

Results of various timing fits are shown in Figure 2. Because of the rather short angular track length of the event ( $18.4^\circ$ ), the timing fit suffers a large degeneracy in the parameters  $R_p$  and  $\chi_0$ ; there is no curvature evident in the  $t_i$  versus  $\chi_i$  plot, meaning that while we do have an estimate of the angular speed  $\omega$  of the light spot across the camera, we have no information about  $d\omega/dt$ . The *best* fit in Figure 2 returns  $\chi_0 = 38^\circ$  and  $R_p = 3.6$  km, but we show that a wide range of values of  $\chi_0$  give acceptable fits. Other values not shown (e.g.  $\chi_0 > 90^\circ$ ) also give reasonable fits.

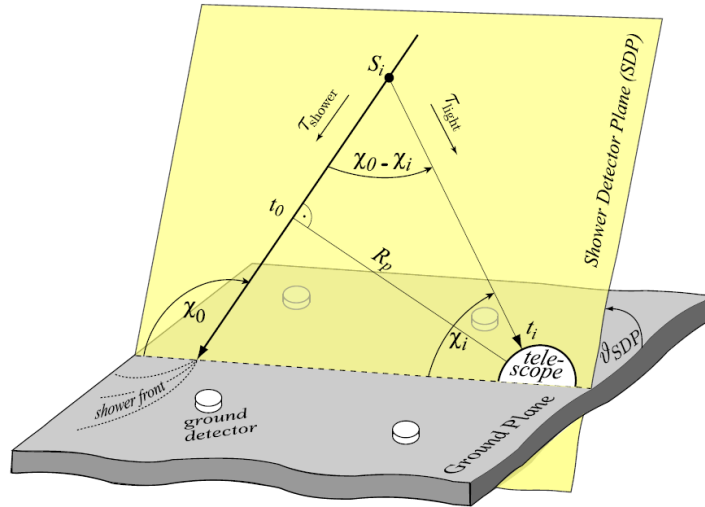


Figure 1: The shower axis and the telescope define the shower-detector plane (SDP). The timing fit returns the axis parameters  $\chi_0$  and  $R_p$ , and the time  $t_0$  at which the shower passes the point of closest approach. (Image from D. Kuempel).

The implication of this degeneracy is that the axis geometry of this event is very uncertain - the shower could be vertical ( $\chi_0 = 90^\circ$  assuming a vertical SDP) with an impact parameter of  $R_p = 2.7$  km, or the shower could be approaching the detector with a zenith angle of  $60^\circ$  (ie  $\chi_0 = 30^\circ$ ) and  $R_p = 3.6$  km.

The latter geometry of an inclined, approaching shower would produce a light signal dominated by Cherenkov light. If this were the case, the claim of Hara et al. of the observation of fluorescence light would be in question. However, Hara et al. correctly point out that there is important information in the *shape* of the light profile recorded by the telescope. We test this in the next section.

### 3 Light Profile

Figure 3 and Figure 4 of [1] give information on the flux of light received by the telescope as a function of time (or angle  $\chi_i$ ). The key point is that the flux profile is rather flat. I have performed some simulations of a shower with a range of axis geometries consistent with the timing fits from the previous section. The simulated shower had a fixed energy of  $5 \times 10^{18}$  eV and a depth of maximum  $X_{\max} = 680$  g/cm<sup>2</sup>. The aim of the exercise is *not* to fit the observed light profile, but to illustrate the change in the light profile shape as a function of the shower geometry.

Figure 3 shows the results of these simulations. We find that flat light profiles are only seen for more vertical showers. Showers that approach the telescope ( $\chi_0 = 50^\circ$  and smaller) produce peaked light profiles, and produce signals contaminated by a large direct Cherenkov light component. The peaked shape of these profiles is a consequence of the narrow angular distribution of Cherenkov light around the shower axis.

### 4 Conclusion

It appears very likely that the signal detected by Hara et al. was one dominated by fluorescence light, and it is reasonable that they lay claim to the first such detection. While the timing information of the event is not sufficient to reconstruct a unique shower axis geometry, the event's light profile is

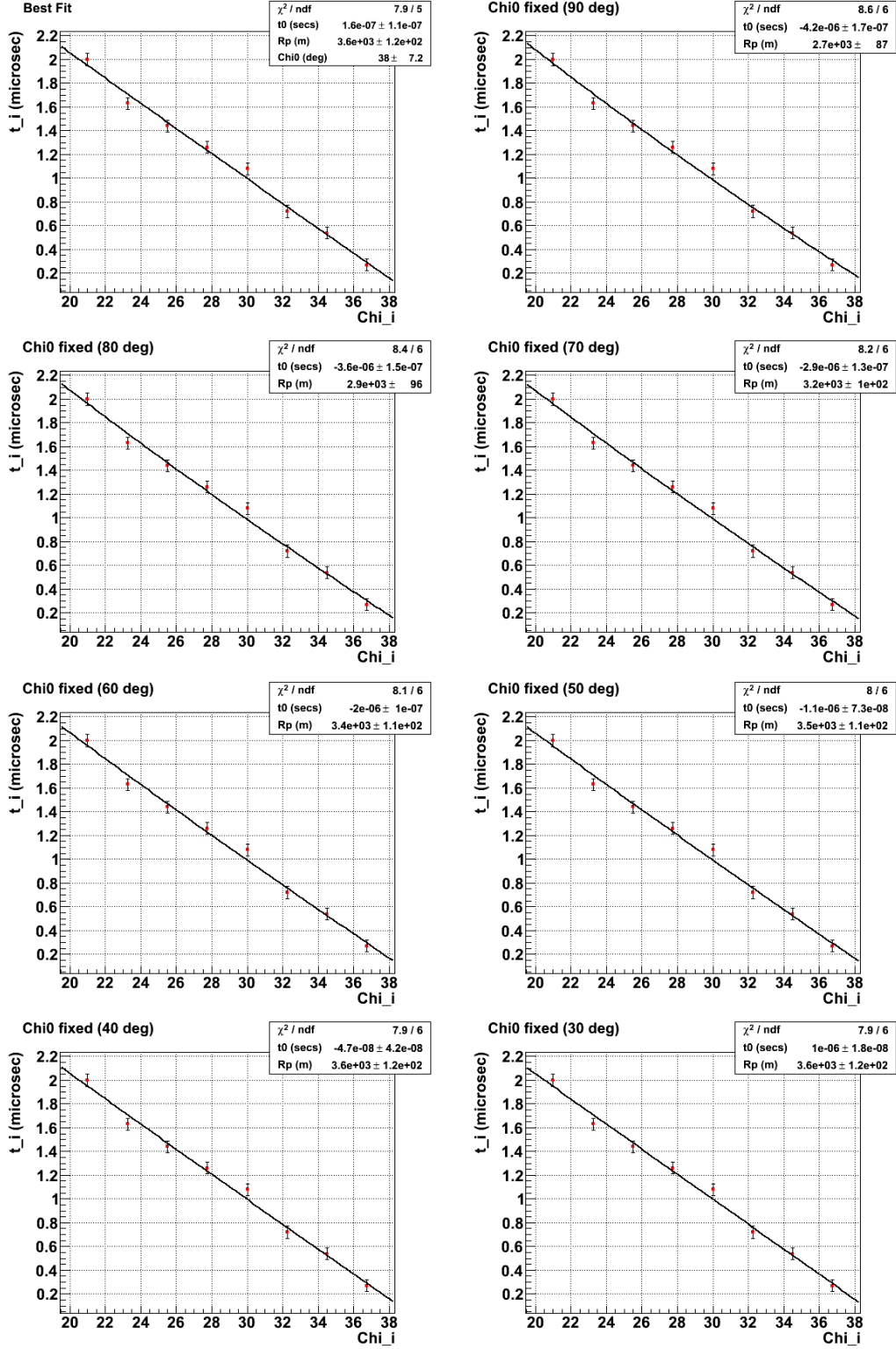


Figure 2: Timing fits for the event. We have assumed a vertical shower-detector plane and timing uncertainty of  $0.05\mu\text{s}$  for each point. The top left figure shows the best fit for  $t_0$ ,  $R_p$  and  $\chi_0$ . The remaining plots show results when  $\chi_0$  is fixed as indicated, and a fit is done for  $t_0$  and  $R_p$ . The short track length of the event precludes a unique reconstruction of the shower axis.

consistent with a fluorescence profile, and quite unlike the peaked profile expected for a Cherenkov dominated signal.

Of course some doubt does remain, and the first *unambiguous* detection of fluorescence light from an air shower was with the Utah Fly's Eye prototype operated in coincidence with the Volcano Ranch surface array in 1977 [3].

The  $5 \times 10^{18}$ eV shower simulated in this note produced a light profile with a peak flux of about  $5 \times 10^{10}$  photons/m<sup>2</sup>/s, the flux observed in [1]. This energy is a factor of two lower than that claimed by Hara et al., but this can be explained by their assumption of a fluorescence yield of 1.9 photons per metre of electron track, which is approximately a factor of two lower than the modern accepted value.

One remaining uncertainty in this energy is the absolute light calibration of the experiment. Hara et al. discuss an inconsistency between the observed light intensity spectrum and that expected from simulations. The inconsistency led to them increasing the observed light fluxes by a factor of 5. The origin of the inconsistency is unclear, but it would probably be safe to say that  $5 \times 10^{18}$ eV is an upper limit to the energy of the observed air shower.

## 5 Acknowledgements

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## References

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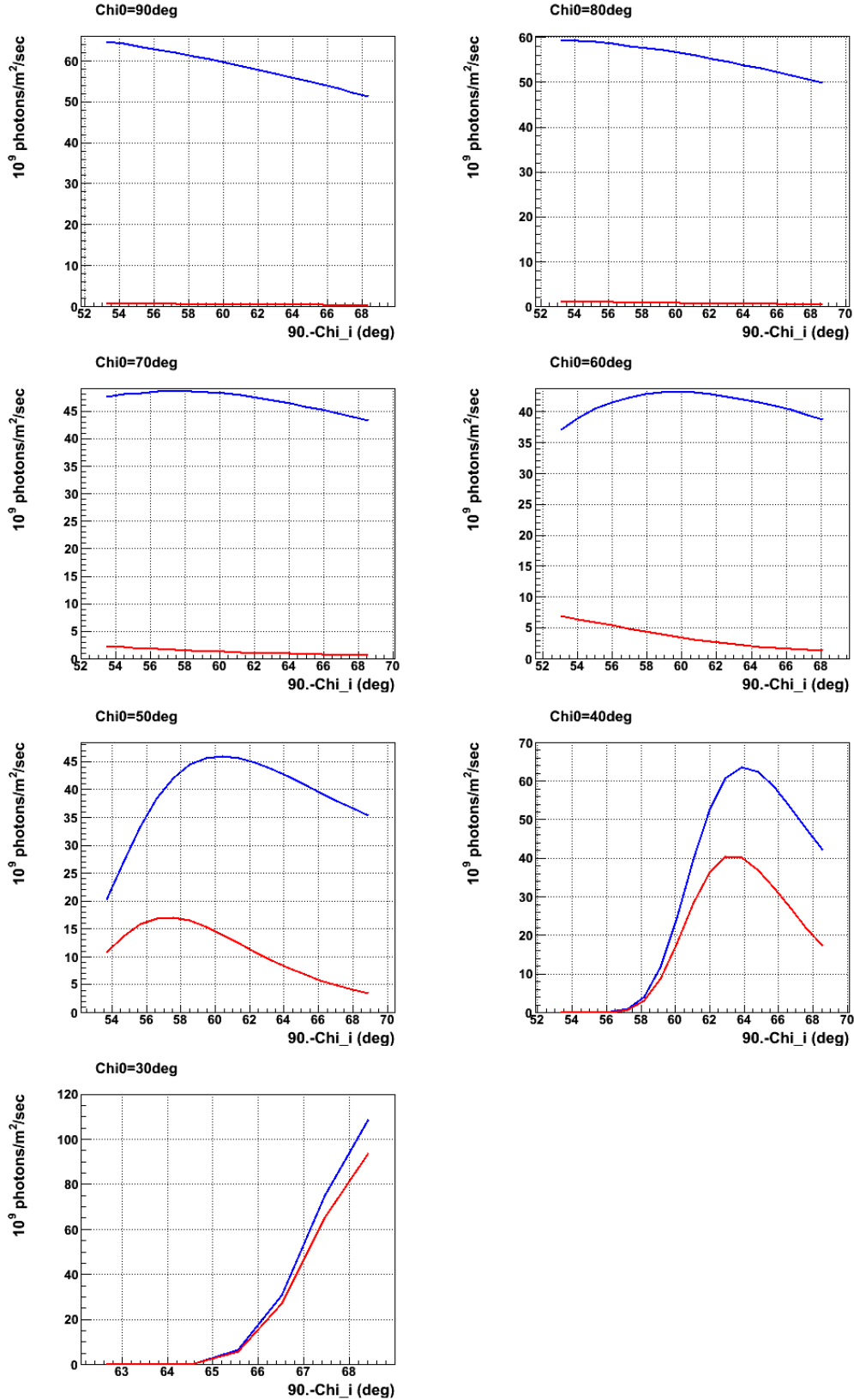


Figure 3: Light flux at the telescope for a  $5 \times 10^{18}$  eV,  $X_{\text{max}} = 680$  g/cm<sup>2</sup> shower for various axis geometries allowed by the timing fit. The x-axis represents the zenith angle of the light spot, given the assumption of a vertical SDP. Blue lines indicate total light flux, and red lines show the contribution from direct Cherenkov light. The shape and intensity of the light profile is a strong function of the event geometry. The flatter light profiles in the first four panels are a better match to the observed light profile.